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TECHNICAL NOTES

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No. 466

ENGINE PERFORMANCE WITH A HYDROGENATED SAFETY FUEL

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SUMMARY

This report presents the results of an investigation to determine the engine performance obtained with a hydrogenated safety fuel developed to eliminate fire hazard. The tests were made on a single-cylinder universal test engine at compression ratios of 5.0, 5.5, and 6.0. Most of the tests were made with a fuel-injection system, although one set of runs was made with a carburetor when using gasoline for the purpose of establishing the comparative performance.

The results show that the b.m.e.p. obtained with safety fuel when using a fuel-injection system is slightly higher than that obtained with gasoline when using a carburetor, although the fuel consumption with safety fuel is higher. When the fuel-injection system is used with each fuel and with normal engine temperatures the b.m.e.p. with safety fuel is from 2 to 4 percent lower than with gasoline and the fuel consumption about 25 to 30 percent higher. However, a few tests at an engine-coolant temperature of 250° F. have shown a specific fuel consumption approximating that obtained with gasoline with only a slight reduction in power. The idling of the test engine was satisfactory with the safety fuel. Starting was difficult with a cold engine but could be accomplished readily when the jacket water was hot. It is believed that the use of the safety fuel would practically eliminate crash fires.

INTRODUCTION

Fire, usually as the result of a crash, is one of the hazards in the operation of aircraft, and the use of gasoline is the greatest factor in creating the fire hazard. The use of a fuel of low volatility, such as Diesel oil, will greatly lessen the danger from fire.

This fact has been one of the incentives to the development of the compression-ignition engine for aircraft use. The high weight/power ratio of the compression-ignition engine, among other factors, has prevented its successful competition with the carburetor-type aircraft engine.

There have been many attempts to produce a relatively safe fuel which could replace gasoline in the conventional engine, with possibly minor modifications to the engine. Sabatier (reference 1) describes several "safety fuels" produced in France both from petroleum and from coal tar. However, difficulties with carburetion have kept them from general use. The latest fuel developed for this purpose is a product made by the hydrogenation process. (See reference 2.) By means of this process a fuel can be produced of nearly any range of volatility desired, and at the same time the antiknock value of fuels of low volatility can be maintained the same as or made even better than the present standards for "aviation" gasolines.

The safety fuels produced by this hydrogenation process cannot readily be used with conventional carburetors because, if the fuel volatility is such that it does not present a serious fire hazard, they are slow to vaporize and mix with the inlet air. The possibilities of the safety fuel could only be investigated by providing for more heating of the fuel if the carburetor were used, or by adopting direct fuel injection, such as is used with compression-ignition engines. The latter method seemed to be the more promising, especially as some experimenting had been done with direct injection of gasoline, and it was accordingly adopted.

This report presents the results of performance tests made by the National Advisory Committee for Aeronautics with a single-cylinder test engine using a hydrogenated safety fuel, as well as results obtained with aviation gasoline under similar conditions. It is the first report of a general investigation of hydrogenated safety fuels started in September 1930.

APPARATUS AND METHOD

These tests were carried out with the N.A.C.A. universal test engine. This is a single-cylinder 4-valve engine of 5-inch bore by 7-inch stroke with a pent-roof type of combustion chamber. (See fig. 1.) There are three spark-plug holes, one directly in the center, and one on each side of the head. The compression ratio, valve lift, and time of opening and closing of each pair of valves are variable. A complete description of this test engine is given in reference 3. The engine is directly connected to an electric dynamometer.

In these tests the central spark-plug hole was used for an injection valve, and spark plugs were used in the other two. Three compression ratios, 5.0, 5.5, and 6.0, were used for most of the test conditions. The lift of all valves was 3/8 inch, and the diameter 1-15/16 inches. All tests were made at 1,500 r.p.m., except one series made to determine the variation of power and fuel consumption with speed. Two different combinations of valve timing were used. With one the inlet valves opened 60° B.T.C. and closed 27° A.B.C., and the exhaust valves opened 47° B.B.C. and closed 52° A.T.C. Thus there was an overlap of 112° between the inlet-valve opening and the exhaust-valve closing. This overlap is not conventional, but it has been found to give both higher power and lower specific fuel consumption when fuel injection of gasoline is used. (See reference 4.) This valve timing permits the engine to be practically completely scavenged by the use of moderate boost pressures at the inlet. A later inlet-valve closing time might be desirable, but it could not be obtained when the inlet valves opened so early. The other valve timing used was considered to be representative of good practice for carbureted engines. The inlet valves opened 15° B.T.C. and closed 45° A.B.C., and the exhaust valves opened 50° B.B.C. and closed 10° A.T.C.

All except one set of runs, when the carburetor and gasoline were used, were made with the fuel-injection system. An automatic injection valve of N.A.C.A. design and a Compur injection pump were used. The injection-valve nozzle had seven orifices arranged to give a fan-shaped spray in the plane of the crankshaft. The valve and nozzle are shown in figure 1. Injection started approximately 70° A.T.C. on the suction stroke and lasted from 70° to 80°.

The outlet of a supercharger was connected to the carburetor through two pulsation-damping tanks, and the supercharger was used to boost the pressure at the inlet when pressures above atmospheric were desired. For all other runs the carburetor and piping were left in place and a valve in one of the tanks was opened to the atmosphere.

The engine was operated with a water-out temperature of approximately 150° F. except for two runs when Prestone was used as the coolant and the temperature at the outlet was maintained at approximately 250° F.

The hydrogenated safety fuel used was furnished by the Standard Oil Company of New Jersey. The flash point of this fuel was about 115° F., whereas that of the aviation gasoline used for comparison was -10° F. Repeated tests at room temperature have shown that if a burning match is dropped into a small open beaker containing the safety fuel the flame will be extinguished, or if the match is not submerged it may continue to burn and draw up fuel like a candle wick. The flame is very slow to spread over the surface of the fuel.

Distillation curves for the aviation gasoline and the hydrogenated safety fuel used are shown in figure 2. The two curves are of similar shape, but that for the safety fuel lies about 140° F. higher than that for the gasoline. The selection of the volatility range for a safety fuel must be a compromise between the desire to safeguard against fire as much as possible and the necessity of providing a fuel that can be vaporized and burned readily in the engine. The aviation gasoline was purchased under specifications requiring an antiknock value of at least 73 octane number. It is rated among the best undoped gasolines available. The antiknock properties of the safety fuel were nearly the same.

A series of three or four runs at different mixture strengths was made for each test condition. The fuel consumption was determined by means of fuel-weighing scales, which started and stopped electrically a revolution counter connected to the engine. The engine torque was obtained from the dial-reading scale of the dynamometer. The ignition timing was adjusted for each test condition for maximum power without detonation.

The data were corrected to standard atmospheric conditions (29.92 inches of mercury and 59° F.) on the assumption that the power varied directly as the pressure and inversely as the square root of the absolute temperature of the inlet air.

RESULTS AND DISCUSSION

The brake mean effective pressure and the fuel consumption obtained with safety fuel and aviation gasoline when using a fuel injection system and operating with a large valve overlap are shown in figure 3. The tests with aviation gasoline were conducted only with atmospheric pressure at the intake whereas the tests with safety fuel were conducted both with atmospheric and with 2 inches of mercury boost pressure at the intake. The results show that for the conditions with atmospheric pressure at the intake the power is from 2 to 4 percent lower and the fuel consumption from 25 to 30 percent higher with safety fuel than with aviation gasoline. The specific fuel consumption using safety fuel is practically the same with 2 inches of mercury boost pressure as with atmospheric intake pressure, whereas the power is considerably more.

With a boost pressure of 2 inches of mercury the maximum brake mean effective pressure at a compression ratio of 5.5 is raised from 150 to 170 pounds per square inch, an increase of 13 percent with an increase in intake pressure of only 7 percent. The rapid rise in power for small increases in intake pressure is due to the improvement in scavenging obtained with a large overlap of the open periods of the inlet and exhaust valves. The effect of this valve timing is discussed more fully in reference 4. The data given for tests with a boost pressure have not been corrected for the power required to drive the supercharger; this would reduce the brake mean effective pressure given by about 2 to 3 percent and increase the specific fuel consumption by the same amount.

The curves for a compression ratio of 6.0 show only a slight improvement in brake mean effective pressure and specific fuel consumption over those for a compression ratio of 5.5, for it was necessary to retard the spark from the position giving maximum power in order to prevent detonation. Both the safety fuel and the gasoline used show approximately the same antiknock qualities.

In order to improve the specific fuel consumption with safety fuel, a few tests were made at a compression ratio of 5.5 with Prestone as a coolant at temperatures of 250° F. instead of water at 150° F. As shown in figure 3, these tests resulted in a large decrease in the specific fuel consumption. The tendency for the fuel to detonate was considerably increased at these high coolant temperatures, but this tendency was eliminated by the addition of ethyl fluid. The effect of the coolant temperature on power and fuel consumption will be further investigated and reported later.

The performance with what was considered to be normal valve timing is shown in figure 4 both for safety fuel using fuel injection and for gasoline using a carburetor. The brake mean effective pressure with safety fuel is seen to be slightly higher than that with gasoline. This increase is due to the fact that operation with fuel injection gives somewhat more power than with the carburetor and not to any superiority on the part of the safety fuel Under the same conditions gasoline will give slightly more power than the safety fuel, as shown in figure 3. The specific fuel consumption at maximum power with safety fuel at a compression ratio of 5.5 is nearly as high with normal valve timing as it is with an overlap of 112°; that is, it is in the neighborhood of 0.66 pound per brake horsepower per hour, but it is possible with normal valve timing to lean the mixture to a fuel consumption of 0.56 pound per brake horsepower per hour at a brake mean effective pressure of 129 pounds per square inch.

Figure 5 shows the brake mean effective pressure and specific fuel consumption with safety fuel at a compression ratio of 5.5 for speeds of 1,200, 1,500, and 1,800 r.p.m. The performance is decidedly better at 1,500 r.p.m. than at the other speeds, probably because of some ramming action due to the length of inlet pipe used. When a few runs were made with no inlet pipe the power was noticeably less.

From the data shown it can be seen that nearly as much power has been obtained with the safety fuel as with aviation gasoline, but that the fuel consumption has always been higher. It may be possible to better the economy either by improving the mixing of the fuel and air in the engine or by making the fuel slightly more volatile.

The exhaust, when safety fuel is used, shows some red flame and smoke, in contrast to the faint blue flame and clear exhaust observed with gasoline. This is further evidence of the incomplete combustion which is indicated by the higher specific fuel consumption. However, there are no particularly disagreeable fumes or odors associated with the exhaust.

The engine started readily with safety fuel when the jacket water was warm, but there was some difficulty in starting with the engine cold. It would probably be necessary to carry a small quantity of gasoline for priming under ordinary service conditions. With normal valve timing the idling characteristics using fuel injection are at least as good as with ordinary carburetor operation, provided that the air is throttled in conjunction with the fuel supply. If a large valve overlap is used the air throttle should be very close to the cylinder. so that no large volume of intake pipe will be at low pressure and fill with exhaust gas during the period that both inlet and exhaust valves are open. With a multicylinder engine there would be some additional complication, for separate air throttles would have to be provided for each cylinder.

The use in aircraft engines of a fuel of low volatility, such as that tested, instead of gasoline would undoubtedly greatly lessen the fire hazard. In the event of a crash in which the fuel tanks burst and spread their contents an explosive mixture of gas and air would not be formed, and if the fuel should ignite at some point the flame would be slow to spread.

CONCLUSIONS

1. Hydrogenated fuel having a volatility range that makes it an acceptable safety fuel can be used in a spark-ignition engine by employing fuel injection, with only a negligible reduction in power as compared with that obtained with gasoline.

2. Satisfactory starting and idling have been experienced in the operation of the single-cylinder test engine with the safety fuel injected into the cylinder.

3. The specific fuel consumption using safety fuel with coolant temperatures of 150° F. is 25 to 30 percent higher than that with gasoline, but with a coolant temper-

ature of 250° F. it is only slightly higher than that with gasoline at normal temperatures and is considered satisfactory.

National Advisory Committee for Aeronautics,
Langley Memorial Aeronautical Laboratory,
Langley Field, Va., May 10, 1932.

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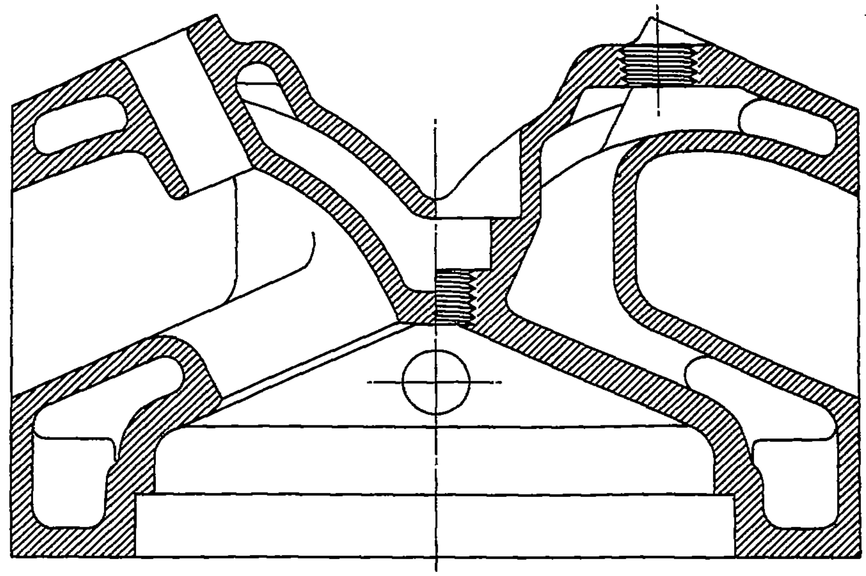
4. Schey, Oscar W., and Young, Alfred W.: The Use of Large Valve Overlap in Scavenging a Supercharged Spark-Ignition Engine Using Fuel Injection. T.N. No. 406, N.A.C.A., 1932.



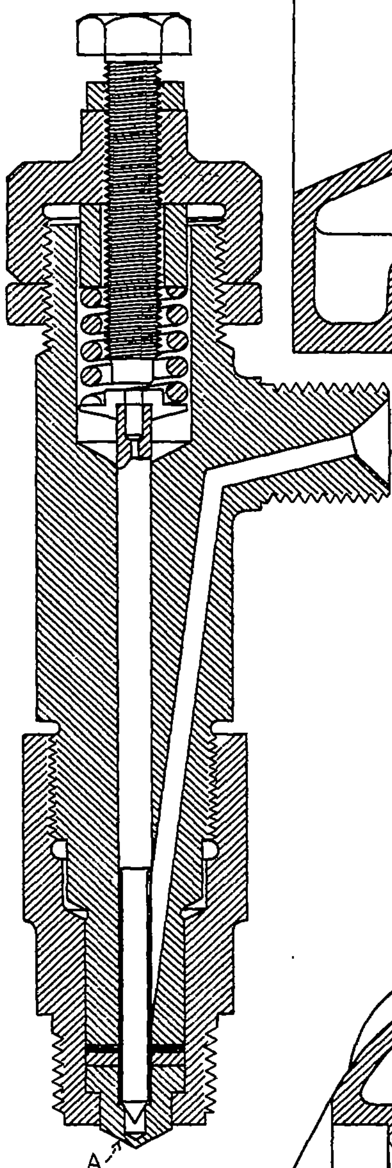
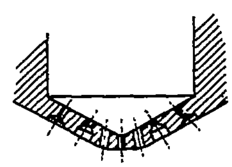
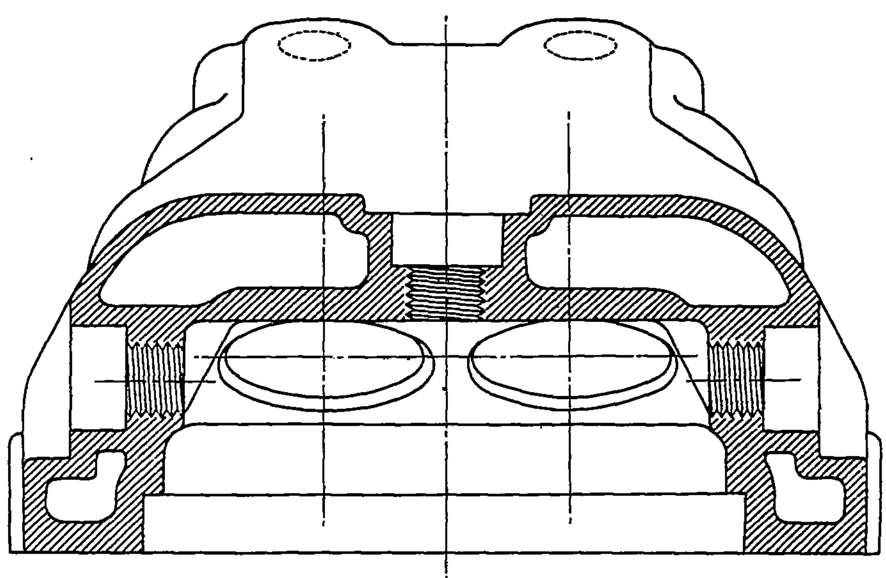


Figure 1.-Combustion chamber and fuel-injection valve used.



Enlarged view of nozzle at A



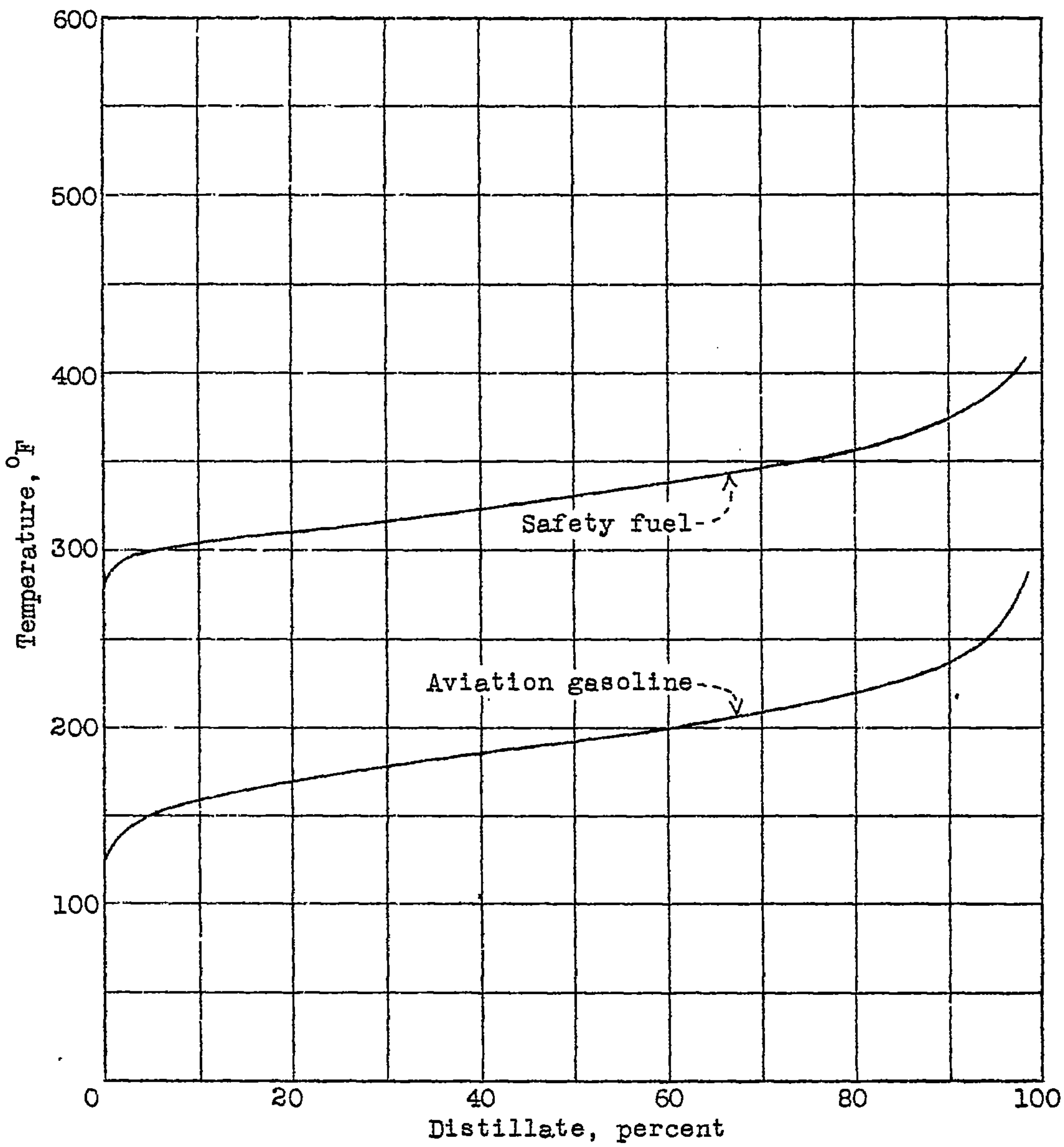


Figure 2.-Distillation curves for the aviation gasoline and the safety fuel used in these tests.

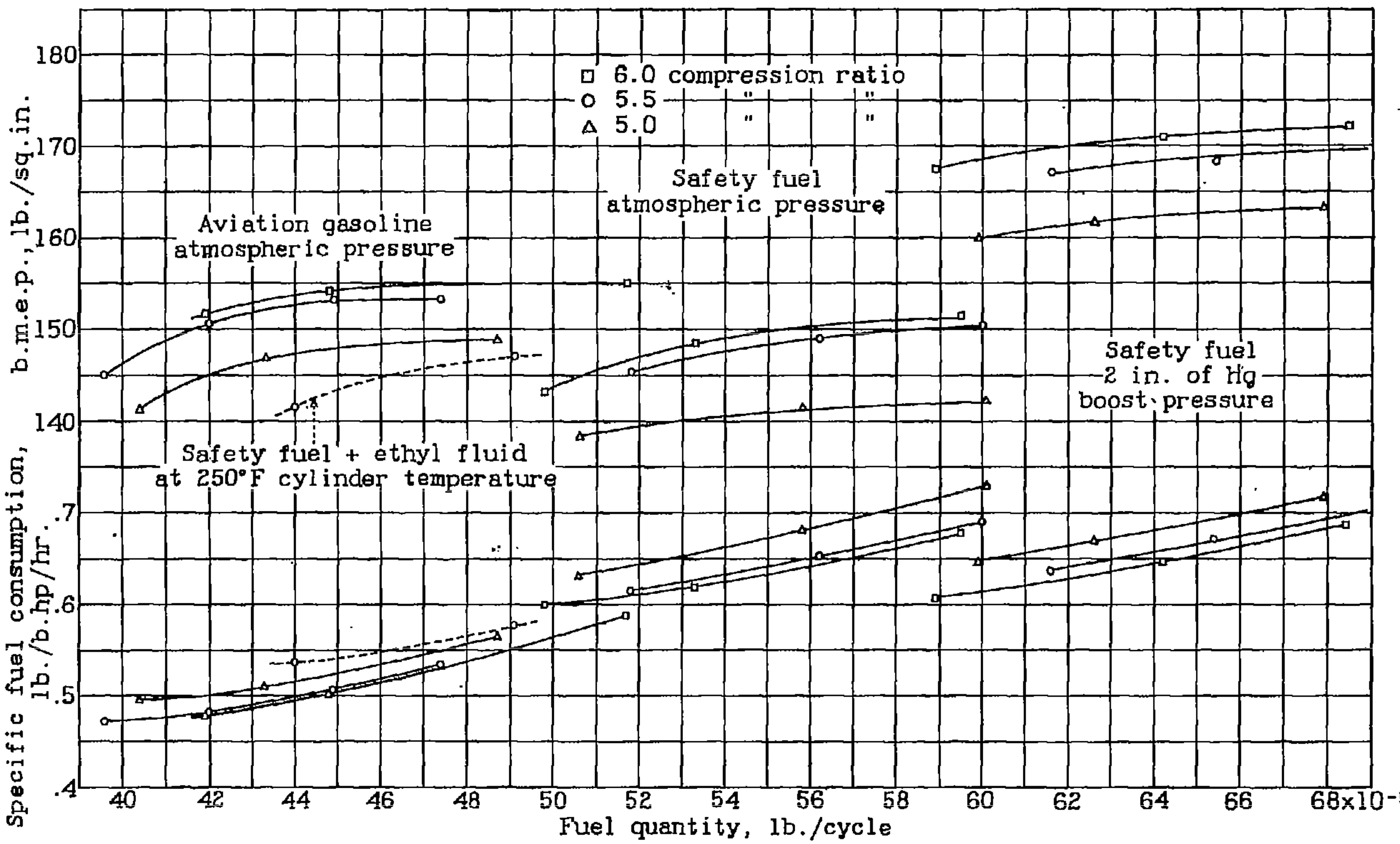


Figure 3.- b.m.e.p. and fuel consumption obtained at compression ratios of 5.0, 5.5 and 6.0 with a valve overlap of 112° using aviation gasoline at atmospheric intake pressure and using safety fuel at atmospheric intake pressure and 2 inches of mercury boost pressure.

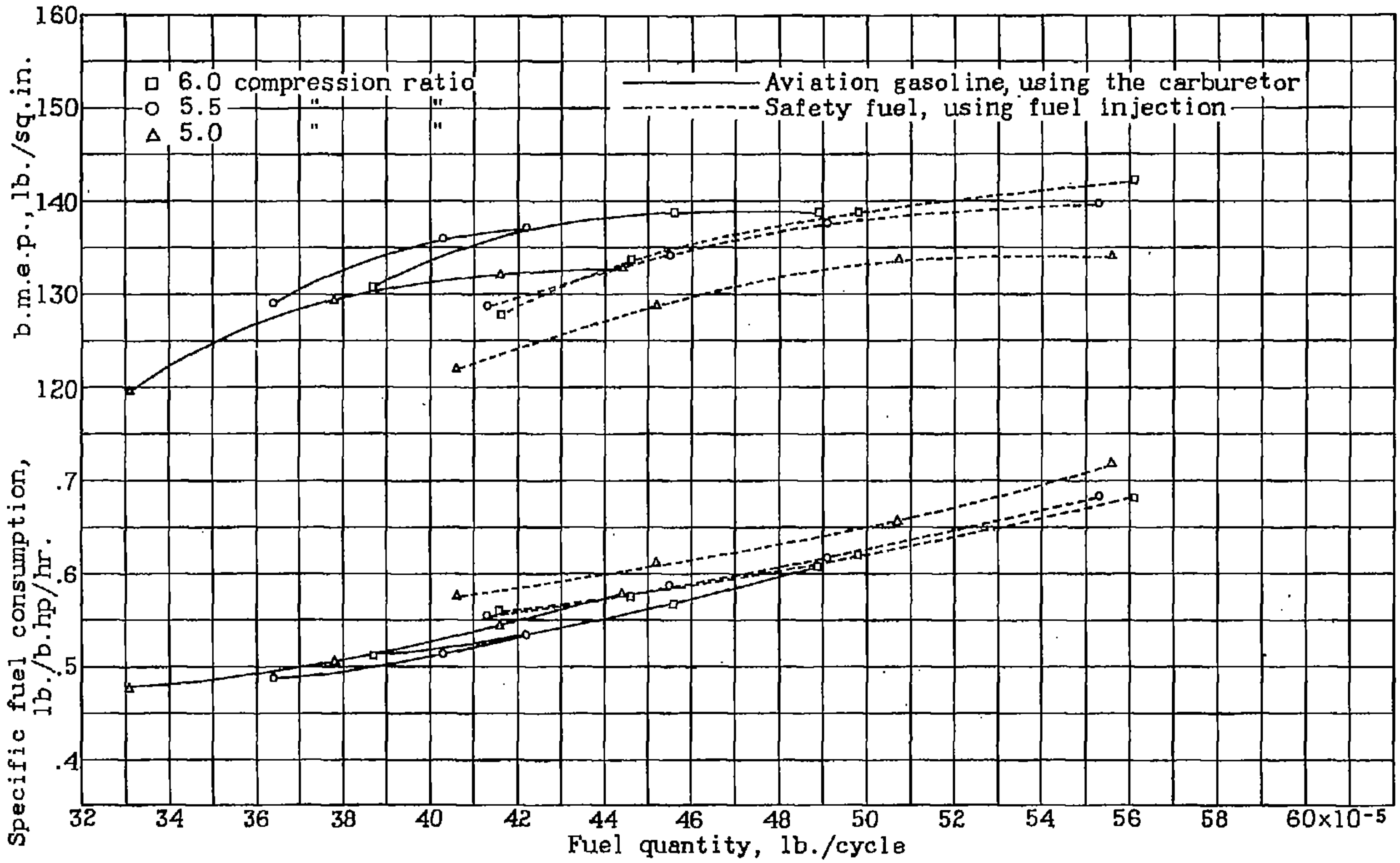


Figure 4.- b.m.e.p. and fuel consumption obtained at compression ratios of 5.0, 5.5 and 6.0 with 25° valve overlap and with atmospheric inlet pressure using aviation gasoline with the carburetor and using safety fuel with the fuel-injection system.

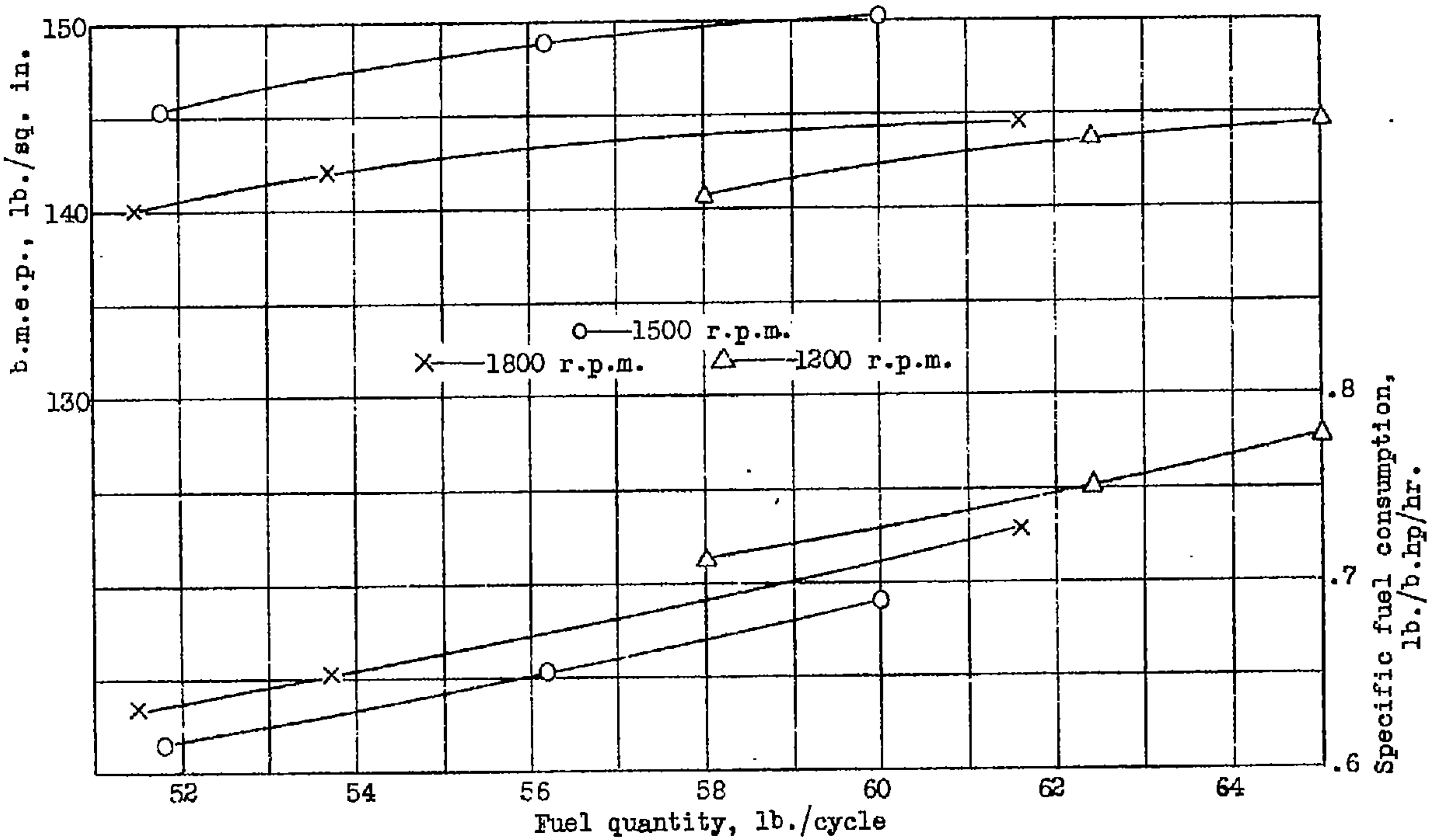


Figure 5.-b.m.e.p. and fuel consumption at speeds of 1200, 1500, and 1800 r.p.m. and at a compression ratio of 5.5 with atmospheric inlet pressure, using safety fuel and a valve overlap of 112°.